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Analysis of integration flow control valve and electronic load controller for micro hydro power plant frequency regulation

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Abstract. Frequency regulation is very important for microhydro power system. Flow control valve (FCV) and electronic load controller (ELC) are common control systems developed for micro hydro power plant (MHPP) with synchronous generator. However, these control systems each other has a drawback in term of frequency response or harmonics issues. This paper proposes an integrate control system, in which FCV and ELC system work together for MHPP in order to obtain a better performance in frequency response and total harmonic distortion (THD). PID and PI controllers were used for FCV and ELC, respectively. The integrated control method influences on the MHPP performance was verified by MATLAB simulation, when the load reduced 10KW in two sequences time. Results of the simulation confirm that the integration of FCV and ELC offered a better trade-off between frequency response and THD issues for MHPP, which cannot be solved by standalone FCV or ELC. By integrating both control systems, they gave the best values for frequency response and THD in around 1.4071 second and 8.57%, respectively.

1. Introduction

The power system should be able to provide power to consumers load with a constant frequency [1]. Swinging frequency should be within the tolerable range of power plants [2]. Frequency control systems in MHPP are basically two kinds, such: governor or flow control valve (FCV) as water flow control system [3] and electronic load controller (ELC) as power electronic control system [4].

Governor or flow control valve (FCV) is a mechanical control equipment, where in the process of control frequency is more emphasis on the regulation of the amount primary energy into the turbine [5]. But this power system has a drawback due to inability when sudden load changes occur. So, it requires a regulation to result a faster response of frequency on the load changes such as ELC [6].

Electronic Load Controller (ELC) is a frequency control equipment that focused on dumping the active power to the dump load (resistive load). If frequency control with ELC run with MHPP, the generator will be work in full rating which is the ELC can drive the frequency return to its normal frequency very fast when the load changing. However, in terms of power savings this equipment is inefficient due to the excess of power is expelled easily to the dump load and mostly run into overheat on dump load [7] and also ELC with trial component has a high level of harmonics on MHPP [8].

Objective of this paper is to integrate FCV and ELC frequency control systems and uses PID for controller for each frequency control system to obtain a better trade-off between frequency response

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and harmonics. The system layout and control scheme integrates of FCV and ELC are developed in MATLAB® Simulink 2014b environment.

2. Methodology

2.1. Synchronous generator

The generator used in this analysis is a 3 phase of synchronous generator. The model shown in figure 1 with the parameters as shown in table 1. Nomenclature: Q = turbine flow (m^3/s), G = Gate Opening (rad), H = Net Head (m), Pm = Power Mechanic (pu), Tw = Time Constant Water (s).

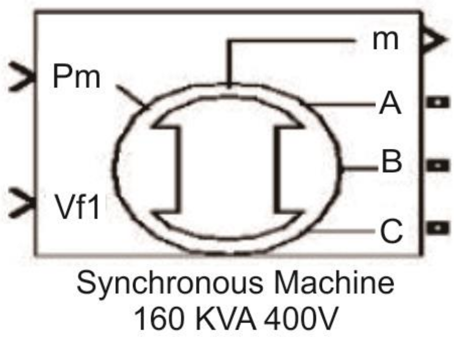

Figure 1. Synchronous generator model.

Table 1. Parameter of synchronous generator.

Parameter	Value
Nominal Power (VA), Line to line voltage (V)	160e3, 400
Frequency	50
Reactance (Xd, Xd', Xd'', Xq', Xq'', XI) (pu)	[2.24, 0.19, 0.13, 1.38, 0.17, 0.07]
Time Constant [Td',Td'',Tq''] (s)	[0.035, 0.011, 0.011]
Stator Resistance (pu)	0.024
Inertia Coefficient (s), friction factor (pu), pole pairs	[4 0 2]
Rotor Type	Salient-Pole

2.2. Excitation system

The excitation modelling designed by IEEE [9], and available in Matlab Simulink inside MathWorks website with AC4A excitation type. The excitation model system is shown in figure 2.

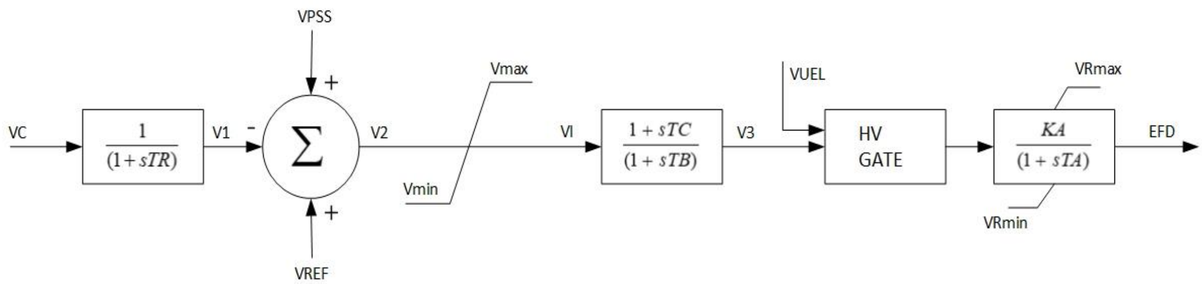

Figure 2. Excitation model system.

The sample data for the AC4A type excitation system is shown in table 2.

Table 2. Excitation system parameter.

Parameter	Value
Tr	0 s
[Ka. Ta]	[200 pu , 0.015 s]
[Kc, Tc]	[0 pu, 1 s]
Tb	10 s
[Vi_{max}, Vi_{min}]	[10, -10] (pu)
[Vr_{max}, Vr_{min}]	[5.64, -4.53] (pu)

2.3. Modelling of Flow Control Valve (FCV) System

There is some of the models needed to create and simulate FCV according to hydraulic turbine and governor modeling designed by the IEEE work group [10], include:

2.3.1. Hydraulic turbine model. Turbine is an important part of microhydro power system that receives potential energy from water and converts it into rotational (mechanical) energy, then this mechanical energy will rotate the turbine axis on the generator. The hydraulic turbine model is depicted as in figure 3. The parameters of hydraulic turbine show in table 3.

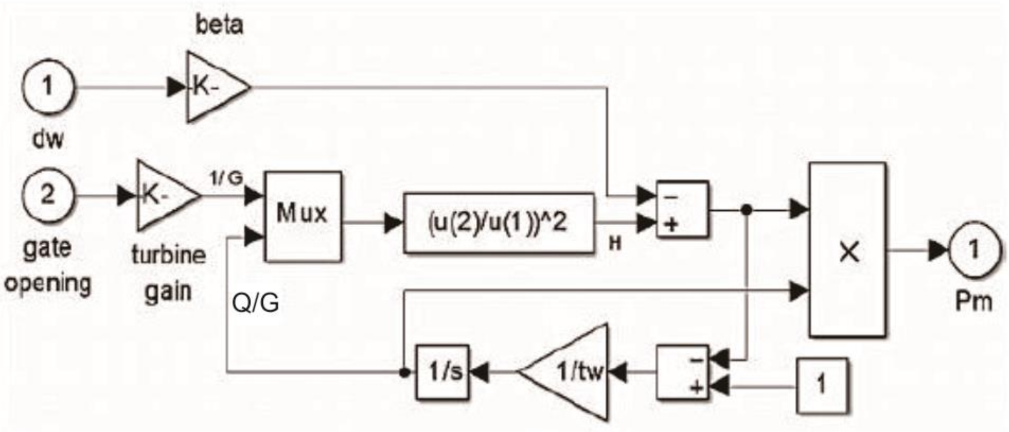

Figure 3. Hydraulic turbine model.

Table 3. Hydraulic turbine parameters.

Parameter	Value
Turbine Flow	0.95 m^3/s
Head base	16.74 m
Penstock Area	0.384 m^2
Length Penstock	60 m
Gravitation	9.8 m/s^2
[G_{max}, G_{min}, beta]	[1,0,0] (pu)

2.3.2. Hydro-electric servo system model as actuator. The motor servo in the FCV used to gate valve according signal from controller to regulate velocity of water flow to stand in set-point value. Hydro-electric servo system shows in figure 4. Hydro-electric servo system parameter shows in table 4.

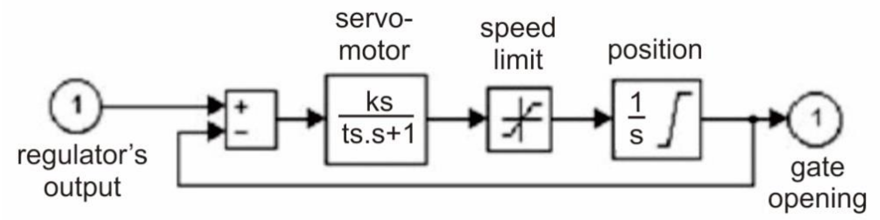

Figure 4. Hydro-electric servo system model.

Table 4. Hydro-electric servo system parameter.

Parameter	Value
Gain constant motor servo	10
Time constant motor servo	0.001
[V_{gmin}, V_{gmax}]	[-0.1, 0.1]

2.3.3. Modelling of PID controller. The PID controller is inserted in the controller system when desired. Improved transitional response as well as steady state responses. PID controller is shown in equation (1). The PID controller has two zeros and one pole. One of the methods used to design PID controllers. It is used to design the PI portion to provide a steady state response, then the PI controller is considered part of the process / plant. In the PD section is designed to improve the transition response.

$$G_o(s) = K_p + K_p s + \frac{K_i}{s} = \frac{K_p S^2 + K_p S + K_i}{s} \quad (1)$$

2.4. Modelling of Electronic Load Controller (ELC) system

Designing the ELC model also uses hydraulic turbine model and hydro-electric servo system model which already been explained on the previous, but both systems are not functioned for controlling the frequency. The model that used for controlling the frequency is needed to simulate ELC is:

2.4.1. AC Regulator Model. AC regulator model uses three phase bidirectioal thyristor is shown on the figure 5. The parameters data for the thrystor component are shown in table 5.

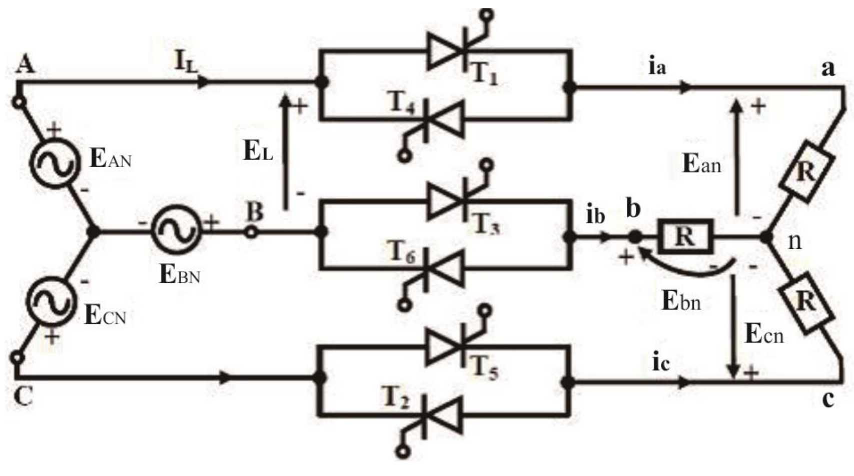

Figure 5. Three phase bidirectional AC regulator circuit.

:

Table 5. Thyristor parameters.

Parameter	Value
Resistance Ron (ohms)	0.001
Inductance Lon (H)	0
Forward voltage Vf (V)	0.8
Initial Current Ic (A)	0
Snubber resistance Rs (ohms)	1e6
Snubber capacitance Cs (F)	inf

2.4.2. Complementary load model. The complementary loads used are resistive loads that is connected in star (Y) connection with the ability to absorb 180 KW of power that is connected with output. The complementary load model is shown in figure 6. The parameters data for the complementary load model are shown in table 6.

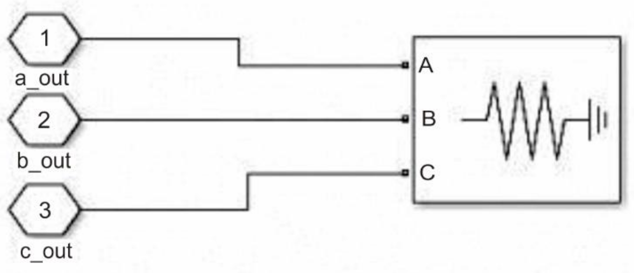

Figure 6. Complementary load model.

Table 6. Complementary load parameters.

Parameter	Value
Configuration	Y (grounded)
Nominal Phase-to-phase voltage Vn (Vrms)	400
Nominal frequency fn (Hz)	50
Active power (W)	180e3
Inductive reactive power Ql (var)	0
Capacitive reactive power Qc (var)	0

2.4.3. PI controller design. PI (Proportional Integral) controller has a transfer function and can be viewed in equation (2) and (3). This controller has a pole at the center point and zero at –Ki/Kp. Due to a pole is very close to the center point compared with zero, this controller is belonging to lagging-phase compensator and it increases the negative angles to angular TKA criteria. Therefore, the PI controller is used to correct the response of steady state of the system.

$$G_c(s) = K_p + \frac{K_i}{s} \tag{2}$$

or

$$G_c(s) = \frac{K_p s + K_i}{s} = \frac{K_p\left(s + \frac{K_i}{K_p}\right)}{s} \tag{3}$$

2.5. FCV-ELC integration system design

After develop the above frequency control systems in standalone form, both of the frequency control can be combined into an integrated control system. The combination of FCV and ELC is proposed to meet the best trade-off between frequency response and THD-V. The integrated scheme for the FCV and ELC can be seen in figure 7.

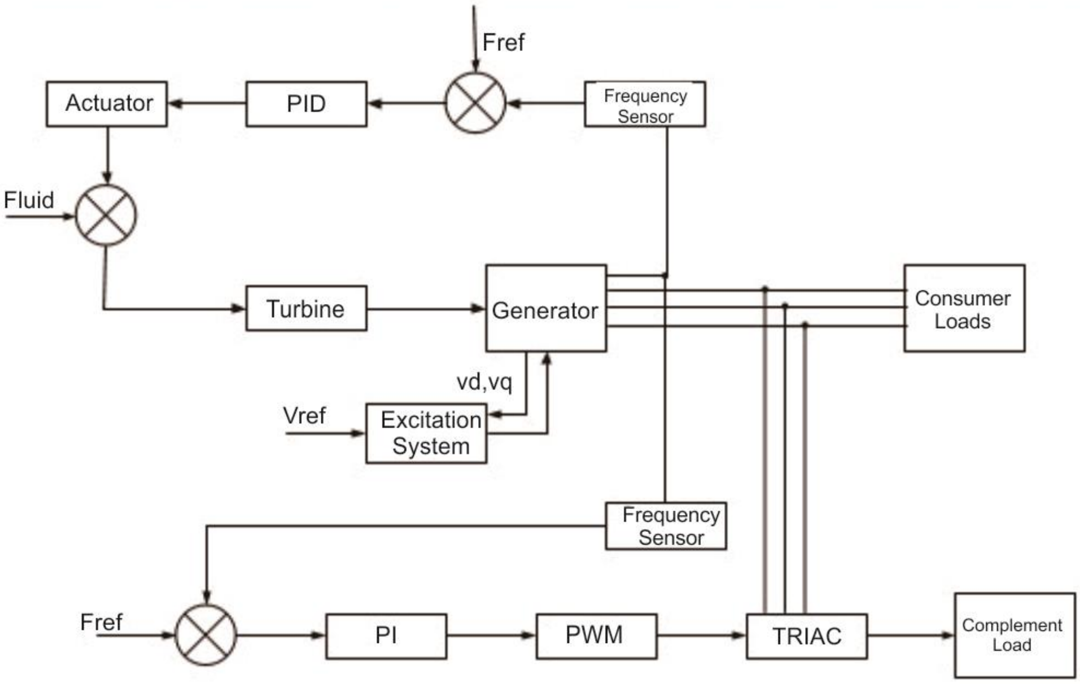

Figure 7. Complement load model.

In figure 7, FCV is developed to control the actuator which regulates the fluid flow rate based on the reference frequency of generator. PID controller is employed to control the performance of the actuator. Accuracy of the actuator will guarantee the turbine receives the fluid amount to rotate in the required frequency. In another side, ELC system control the compliment load based on the change of consumer loads to maintain the generator frequency in its bounded frequency. In the task the ELC system performance is improved by employing PI controller. Both of the control systems performance are investigated under the change of consumer loads.

3. Results and Discussion

In order to verify the proposed control system, each type of the control system was simulated and verified in details to answer the objectives of the study. The consumer loads were assumed to reduce two times in 10KW at 10th and 20th seconds as seen in figure 8 for all types of simulation.

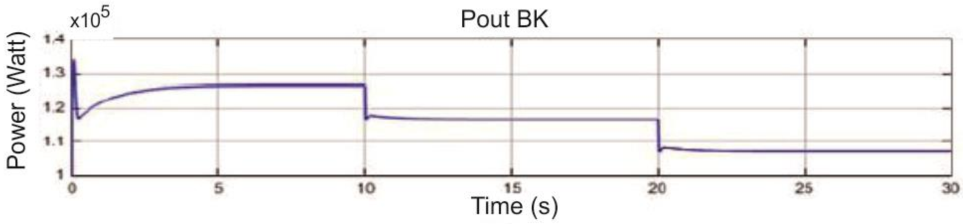

Figure 8. Consumer power load FCV system.

The first verification with the load was done for FCV system with the results as shown in figure 9. Figure 9 shows that there was a change in the current of the phase to ground when the consumer loads reduce in 10 KW at the 10^{th} and 20^{th} seconds. However, for the phase to ground voltage remains stable in $230V_{rms}$.

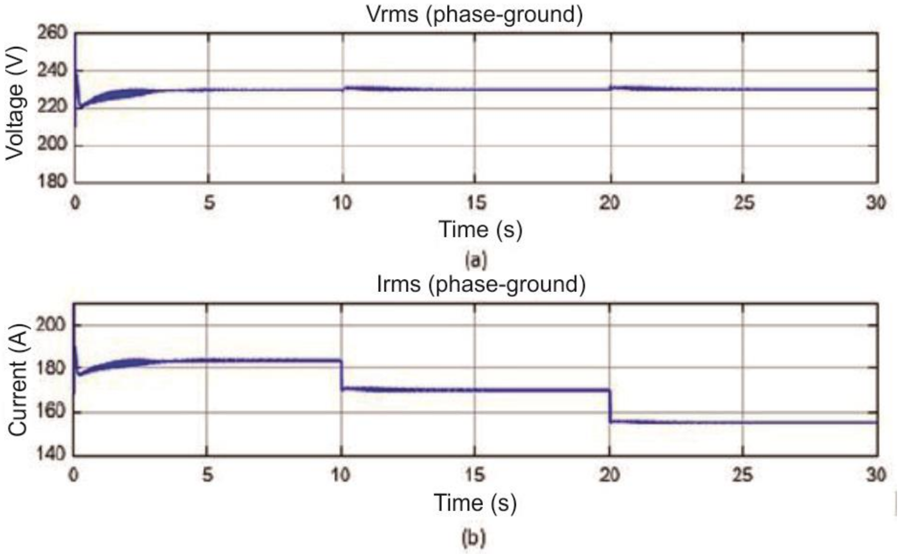

Figure 9. (a) V_{rms} and (b) I_{rms} of FCV system.

The reduction of the load may cause the change of power mechanic and the increase of frequency to around 50.51 Hz in figure 10 and figure 11, respectively. From those figures, it can be seen that, the FCV result a higher change of frequency, but it can ensure the frequency to return to the nominal value of 50 Hz by reducing the valve opening of the turbine, and decrease the turbine generated power. This type of control system was very capable to result a very low THD, but it was very slow to return to its normal frequency.

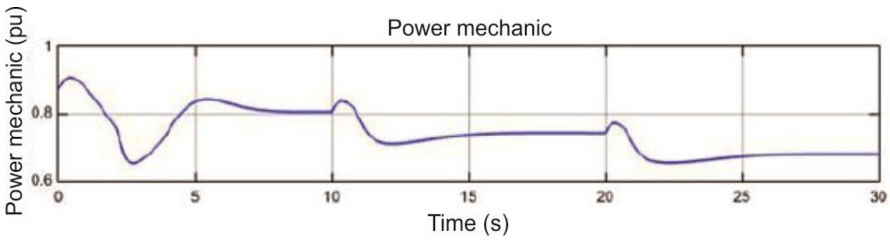

Figure 10. Power mechanic of FCV system.

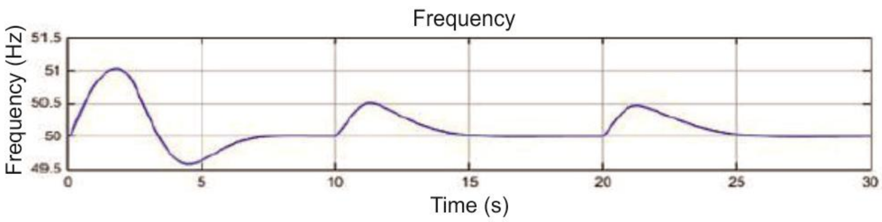

Figure 11. Frequency of FCV system.

While, simulation results of verification for ELC system in the MHPP system model can be seen in figure 12 to figure 14. In figure 12, there was a reduction in the consumer load of 10 KW that also affected on V_{rms} and I_{rms}. However, the ELC responded the change of load by enlarging the aperture angle of the regulator and the power that can be applied to the complement load. Such that, the total power generated by the generator remains constant. Consequently, impact of the load change on I_{rms} were not significant as the MHPP with FCV system. In the contrary, the ELC system result THD higher than the FCV.

Power mechanic and frequency of the MHPP with the ELC system can be seen in figure 13. Figure 13 shows that a load reduction in the MHPP with the ELC system did not cause any change in power mechanic. Because there is no frequency feedback from the ELC system to governor system to adjust the turbine rotation. The ELC system works to adjust the frequency change to return to the normal frequency of 50 Hz. As shown in figure 14, with the ELC system capability, the generator capable to return to its normal frequency much faster, around 11 times compared to the FCV systems.

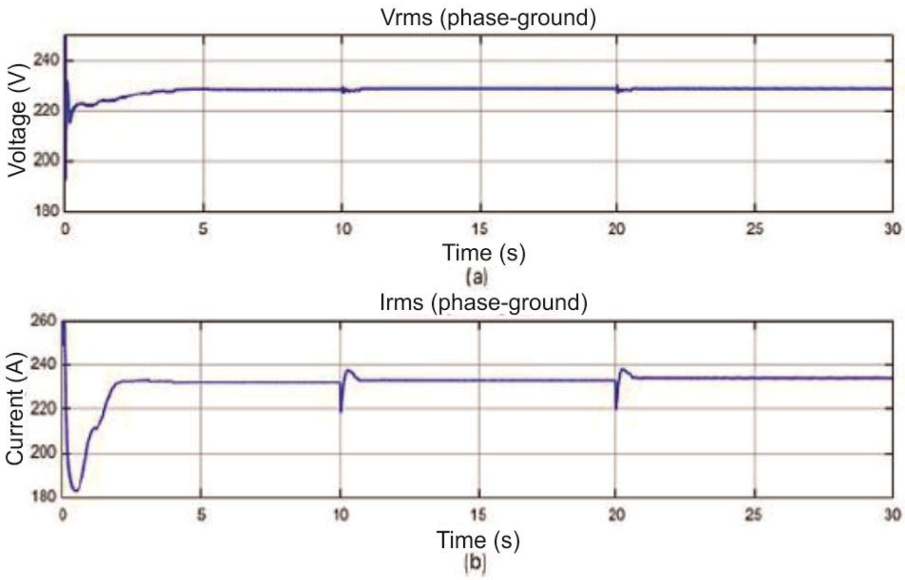

Figure 12. (a) V_{rms}, (b) I_{rms} of ELC.

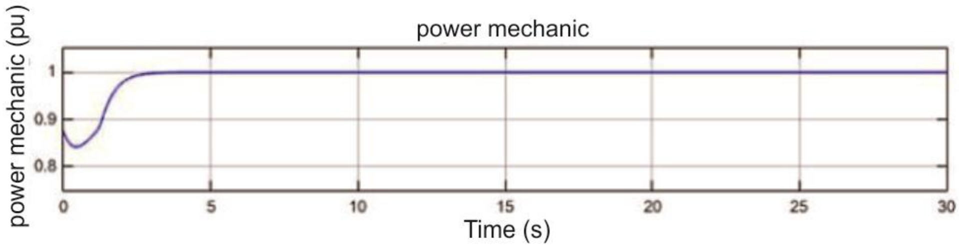

Figure 13. Power Mechanic of ELC system.

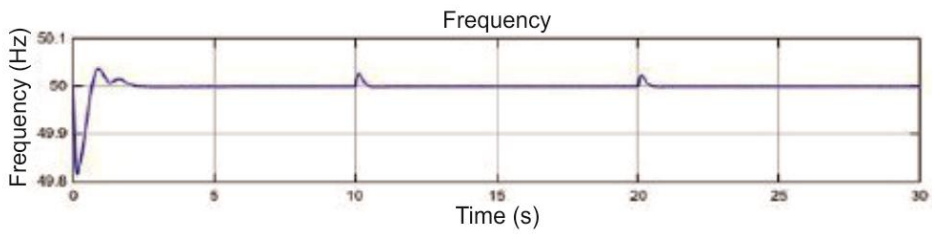

Figure 14. Frequency of ELC system.

Then, results of the integration between the FCV and ELC systems on MHPP system are shown as in figure 15 to figure 18. Figure 15 indicates that no significant change in the phase to ground current when a consumer loads reduction occurred in 10 KW at the 10th and 20th seconds, and for the phase to ground voltage remains stable at 230 V_{rms}. As shown in figure 16, when consumer load reduced in 10KW, the ELC worked by enlarging the aperture of the ac regulator angle and the power can be adjusted to the complement load so that the total power generated by the generator remains constant. However, the existence of FCV caused the power mechanic influencing significantly with lower THD.

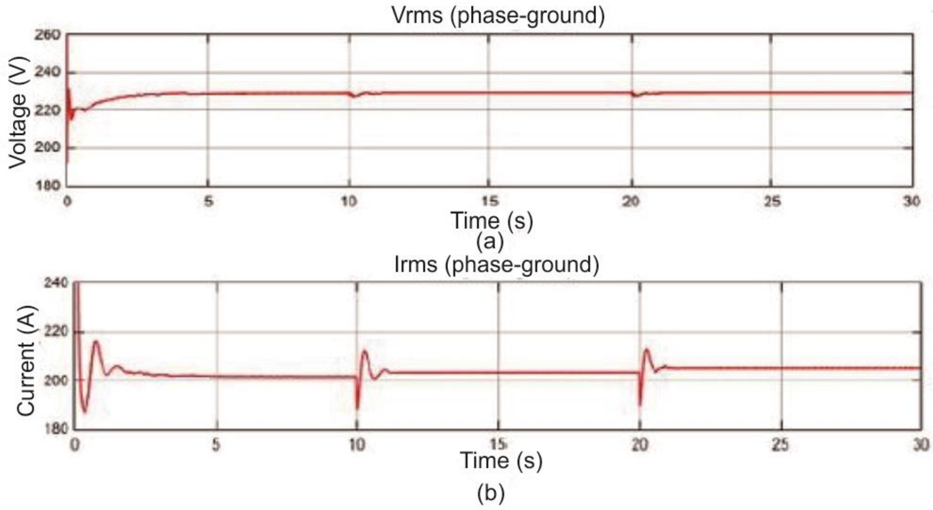

Figure 15. (a) V_{rms}, and (b) I_{rms} of FCV-ELC integration system.

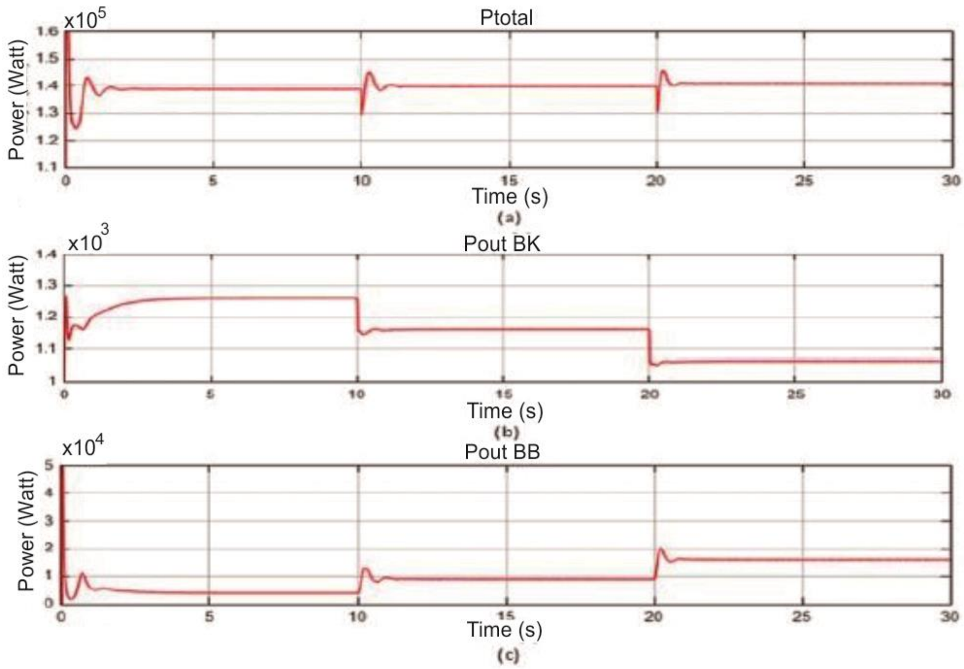

Figure 16. (a) Power Consumer Loads (b) Power Complement Load (c) Total Power of Integrated FCV-ELC system.

Following a significant change in its power mechanics, it also shows the performance of the FCV systems to manage changes in frequency to return to the normal value by reducing the valve opening on the turbine. But, the integrated cannot manage the frequency response faster as the ELC response.

Figure 18 shows that the frequency response capability to return to the nominal value takes 1.3575 second.

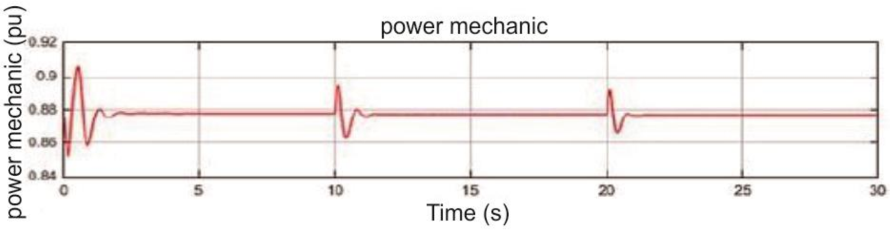

Figure 17. Power mechanic FCV-ELC integration system.

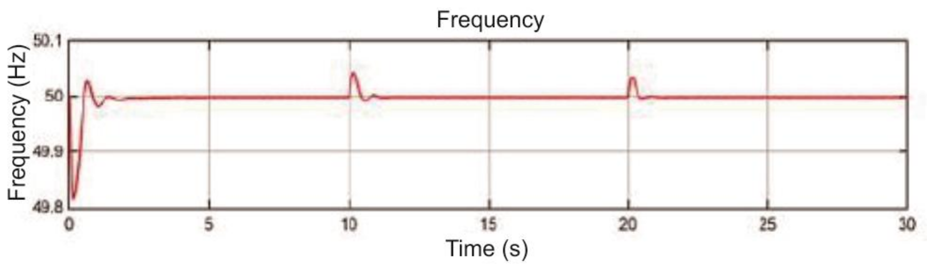

Figure 18. Frequency of FCV-ELC integration system.

From figures 8-18, frequency performance of the integrated control using FCV-ELC compared to the standalone FCV and ELC is summarized in table 7. While, summary of THD-V of the integrated FCV and ELC compared to the standalone controller system can be seen in table 8.

Table 7. Frequency performance of the integrated FCV-ELC on FCV and ELC.

Performance	FCV	ELC	FCV-ELC
Settling Time (s)	5.4548	0.4046	1.3573
Settling Min (Hz)	49.99	50	49.993
Settling Max (Hz)	50.53	50.03	50.042
Overshoot (%)	1.06	0.06	0.084
Peak (Hz)	50.53	50.03	50.042
Peak Time (s)	1.3071	0.0944	0.1519

Table 8. Summary of the THD-V of the three.

No	Consumer Load (KW)	THD-V		
		FCV	ELC	FCV+ELC
1	128	0.17%	10.65%	8.4%
2	118	0.07%	12.24%	9.75%
3	108	0.10%	13.67%	11.62%

THD-V in the FCV-ELC integration system decreased after both systems were integrated for both the first load reduction and for the second load reduction, for the first load reduction the THD-V value reached 7.75% and for the second load reduction the THD-V value reached 11.62%, with 5 cycle sample.

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4. Conclusion

Integration of FCV and ELC to improve the performance of the MHPP in term of frequency and THD-V has been done successfully. Simulation on the MHPP model test shows that the generator is capable to generate electrical power more than 128 KW with 50 Hz of frequency and 230 V of V_{rms}. Results of the simulation confirm that the integration of FCV and ELC offered a better trade-off between frequency response and THD-V issues for MHPP, which cannot be solved by standalone FCV or ELC. By integrating both control systems, they gave the best values in term of frequency response and THD-Vin around 1.4071 second and 8.57%, respectively.

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References

[1] Schener L G and Tambara R V 2016 Voltage and Frequency Regulation of Standalone Self-excited Induction Generator for Micro-hydro Power Generation using Discrete-time Adaptive Control *IET Renewable Power Generation* 10 4 p 531-540

[2] Marinescu C and Serban I 2009 Analysis of Frequency Stability in A Residential Autonomous Microgrid Based on A Wind Turbine and A Microhydro Power Plant IEEE Power Electronics and Machines in Wind Applications Conference Lincoln NE, USA, 24-26 June

[3] Blegojevic V and Stojiljković M 2013 Guide Vane Position Control of the Mini Hydro Power Plant with the Reduction of the Impact of Disturbances on the System FactaUniversitatis Series: Mechanical Engineering 11 1 p 55-64

[4] Gyawali N P 2016 Universal Electronic Load Controller for Microhydro Power Plant 12th IEEE Int. Conf. on Control and Automation (ICCA) Katmandhu, Nepal, 1-3 June.

[5] Borkowski D and Wegiel T 2013 Small Hydropower Plant with Integrated Turbine-Generators Working at Variable Speed IEEE Trans. on Energy Conversion 28 2 p 452-459

[6] Sandy A 2010 Studi Pengontrolan Beban Elektronik Pada Pembangkit Listrik Tenaga Mikrohidro Seloliman, Trawas Kabupaten Mojokerto Electrical Engineering Department, ITS, Indonesia Undergraduated Thesis

[7] Singh A K 2013 Modeling and Simulation of Micro Hydro Diesel Hybrid Power Systemfor Localized Power Requirement Using MATLAB/Simulink Master of Power Engineering, Jadavpur University Thesis

[8] Mashar A and Sodiq D 2011 Analisis Hamornisa Elektronic Load Control (ELC) PadaPembangkit Listrik Tenaga Mikro Hidro (PLTMH) Poli-Teknologi Politeknik Negeri Bandung 10 2

[9] IEEE 2005 IEEE Recommended Practice for Excitation System Models for Power System Stability Studies IEEE Standard 421 5 (Revision of IEEE 521.5-1992)

[10] IEEE 1992 Hydraulic Turbine and Turbine Control Models for Dynamic Studies IEEE Trans. on Power Systems 7 1 p 167-179